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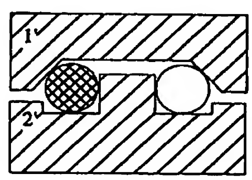

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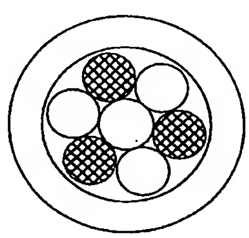

(57) Abstract

The invention concerns a method to machine roughly shaped ball blanks of hard materials to the shape of spheres with a high sphericity and surface finish. According to the invention, balls of hard materials (e.g. ceramics) are brought to slide against already spherical balls of softer materials (e.g. steel) in a grinding cell (1, 2) under the addition of grinding agents, e.g. diamond grits. With the grinding cell, alternatingly positioned hard and soft balls are pressed against each other in a ring shaped track, defined by the facing surface of two rotationally symmetrical bodies, which are rotated relative to each other, and which exerts both a force axially against the balls, and a force radially inwards, or outwards.

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Method and means for grinding balls of ceramics or other hard materials to spherical shape

The present invention relates to a method of grinding and polishing spheres of hard materials according to the preamble of claim 1, and an apparatus for the realisation of the method according to the preamble of claim 6.

Balls of hard materials, such as cemented carbides or ceramic materials are being increasingly used in various applications. For example, such balls are used in fully ceramic ball bearings and in so called hybrid ball bearings, combining ceramic balls with races of ball bearing steel. Hybrid ball bearings are used in applications involving small tolerances and high rotational speeds, e.g. highly efficient machine tools or turbines. Ceramic bearings do also withstand higher temperatures than metallic bearings; they are more chemically resistant and are also less dependent on continuous lubrication with oil or grease, which is advantageous in the chemical or food industries.

This development of bearings of hard materials also requires better machining methods. In the manufacturing of balls of hard materials, grinding and polishing methods are of fundamental importance to achieve high sphericity and surface finish. Today, lapping between rotating disks is the most commonly used method to machine ceramic balls.

The conventional machining methods do however suffer from problems such as low machining rates and high tool wear, making the machining sequences slow and expensive parts of the manufacturing route for ceramic balls.

The manufacturing of hard balls of ceramic materials or cemented carbides are commonly made through the densification of pre-shaped powder bodies with high pressures and temperatures. This leads to dense and strong balls with roughly spherical geometry and a coarse surface. Therefore, subsequent grinding and polishing is required to achieve high sphericity and surface finish. This grinding is time-consuming and wears down the machining tools heavily, contributing to the high product prices.

To minimise the need of machining the balls in the dense and hard final state, efforts are made to grind the pre-shaped balls to highest possible sphericity

before densification. The possibility of assisting the mechanical machining with chemical etching has also been proposed.

In the grinding and polishing of materials with mechanical methods, grinding agents containing hard particles that cut the surface to be machined are often used. The grinding agent may be bonded to the surface of a tool, or may move freely between the tool and the surface to be machined. The machining of hard and thereby often brittle materials is generally more difficult, expensive and time-consuming than the machining of softer and more ductile materials. Because of the high requirements on the abrasive grits, and on the hardness and wear resistance of the tools, only the very hardest materials (often diamond) can be used. Still the wear of the tools often becomes unacceptably high and the risk of surface fracture of brittle materials is critical.

It has been shown in N. Axén, S. Jacobson, S. Hogmark, Influence of hardness of the counterbody in three-body abrasive wear - an overlooked hardness effect, Tribology Int. 1994, 27, p. 233-241, that when a hard material is brought into sliding contact with a softer material, under suitably chosen geometrical conditions and in the presence of hard grinding grits, the hard material tends to wear faster than the soft material. The reason for this is that the hard grits become embedded in the softer surface and cut into the harder material. The softer surface thereby takes the function of a tool, which supports and holds the abrasive grits. This effect offers a principle for the machining of a hard material by sliding it against a softer surface in the presence of hard abrasive grits. This principle is exploited e.g. in lapping.

Grinding of balls of steel is normally performed with a technique based on lapping. Ball blanks are lapped between rotating lapping disks with U- or V-shaped circular tracks in which the balls are driven over the counter surface in a spiroidal motion that provides a simultaneous rotation of the balls and a grinding against the surfaces of the disks. This technique is well developed and used for the grinding of steel balls, see US 3-667-168, A, 1972.

Another method to machine balls is the so called magnetic fluid grinding technique, which has been developed in Japan and England, see T.H.C. Childs, Magnetic fluid grinding of ceramic balls, Grinding, IDR 3/94, 120-123. With this method balls are ground in a magnetic fluid containing grits in a grinding cell having such a geometry that the balls are forced to rotate in many different directions, leading to an even distribution of the material removal over the surface. With the method the balls are machined against the surfaces of the grinding cell through the grits available in the magnetic fluid.

There are also a large number of techniques based on the principle of grinding balls, under suitably chosen geometrical conditions, against grinding tools of the type grinding discs of very hard materials, see e.g. SU 1123-842-A and SU 1787747-A1.

Currently available methods to grind balls are well optimised for the grinding of metal balls, primarily steel balls. For the grinding and polishing of hard, brittle ceramic balls, these methods carry the disadvantage of being slow and expensive, and surface finish and ball size are difficult to control. The grinding of brittle materials also requires a mild surface treatment to avoid the initiation of cracks, which makes grinding with grinding discs unsuitable.

Today, the industrially most used method of grinding spheres of hard materials is essentially the same as the technique used for the machining of traditional ball bearing balls of steel, i.e. lapping against concentrically rotating disks with grooves. The disadvantages with this technique are primarily the low machining rates and the wear of the lapping equipment, primarily the discs. The method is therefore slow and expensive.

A novel method for the grinding of balls should possess the following properties:

1) The method should enable rapid and cheap grinding and polishing.

2) The technique should offer possibilities to control the size of the spheres and the surface finish.

3) The technique should be easily industrialized for large scale grinding of balls.

It is therefore the object for the present invention to provide a method of grinding and polishing balls to high surface smoothness and sphericity, and an apparatus for the realisation of the method. The method is mechanical and based on the grinding of balls of hard materials against balls of softer materials through the addition of grinding agents in an apparatus in which the balls are pressed against each other and forced to rotate and slide relative to each other.

The objects of the invention are achieved with a method according to claim 1, and an apparatus according to claim 6.

Below, the invention will be further described with reference to the accompanying drawings, wherein:

Fig. 1a and 1b illustrate schematically, in cross-section and in a plane view from above, the method of the invention put into practice in a first version of the apparatus;

Fig. 2a and 2b illustrate schematically the method applied in a second version of the apparatus, in views corresponding to the views of Fig. 1;

Fig. 3 and 4 illustrate schematically alternative geometries of grinding cell incorporated in the apparatus.

The method is based on the principle of grinding hard balls, such as ceramic balls, from coarsely shaped blanks, against already manufactured softer balls, such as steel balls, to which grinding particles, e.g. diamond powder, are added. This can take place in a grinding cell, which may be of different geometries. The grinding cell consists of an upper and a lower part, both of

rotational symmetry, which are at least partially manufactured of an elastic material of suitable hardness, preferably softer than the softer balls. An elastic material is referred to as a material, which regains its original shape after deformation.

A number of balls of alternatingly hard and soft materials are positioned in a ring in a race-rack within the grinding cell, in such a way that each hard ball is in contact with at least one soft ball. It is an advantage to sort the balls so that every second ball is hard and every second soft. For the grinding of ceramic balls, softer balls of ball bearing steel may be used.

The dimensions of the grinding cell racetrack are adopted to the size and number of the hard and the soft balls, so that when the parts of the grinding cell are pressed together, the balls are pressed against the walls of the grinding cell, and hard ball presses against soft ball in a ring.

As the upper and the lower parts of the grinding cell are driven to rotate relative to each other, the friction between the balls and the grinding cell force the balls to follow the grinding cell in its rotation and thereby to slide relatively to each other. As grinding grits are added to the system, either in the form of dry powders or as slurries, the grits will stick to the surface of the softer balls and machine the surface of the harder balls. This implies a suitable choice of material for the grinding cell walls, so that the friction between the walls and the balls is higher than that between the balls.

The geometry of this type of grinding cell should be such that the balls are forced to rotate essentially equally in all directions, for the machining rate to distribute equally over the surfaces of the balls. The size of the softer balls and the geometry of the grinding cell determine the size of the hard balls. The grinding rate of the hard balls is reduced when their size is reduced to that of the softer balls, since the force pressing them together thereby falls.

The grinding method according to the invention may use both coarse and fine, hard and soft particles. Hard particles generally produce higher machining

rates, while smaller and softer particles give smoother surfaces. Machining rate and surface finish are controlled by suitable choices of grinding agent, the magnitude of the applied load, the rotational speed, and the number of balls in the grinding cell.

Described below, and in connection with the drawings, contemplated embodiments of the grinding cell as part of the apparatus to carry out the invented grinding method are described.

Fig. 1a schematically shows a cross-section of a first embodiment of a grinding cell, comprising two axially on top of each other journalled rotationally symmetrical bodies, 1 and 2. The bodies 1 and 2 are designed to define a circular racetrack 3 therebetween for the hard ball blanks 4 and the softer balls 5. One of the bodies, 1 or 2, of the grinding cell is propelled relative to the other, and during the process a load is applied axially towards the other body. The grinding cell according to Fig. 1a and 1b is provided with a central core 6, the geometry of which being designed to exert a pressure directed radially outwards during the process. Fig. 1b illustrates schematically in a plane-view from the top, how the hard ball blanks 4 and the softer balls are arranged alternatingly in the lower grinding cell body 2.

In fig. 2a and 2b an alternative embodiment of the grinding cell is illustrated schematically. The grinding cell of Fig. 2 differs from that in fig. 1 mainly in that the rotationally symmetrical bodies 1' and 2' are designed to exert a radially inwardly directed pressure or load during the process.

In the above described embodiment, the circular racetrack 3 has a trapezoid cross-section, wherein the ball blanks and the softer balls are in contact with three sides of the cross-section of the racetrack. In the first embodiment, the racetrack 3 has an inner periphery which diverges from the central axis of the grinding cell, while in the second embodiment the outer periphery of the racetrack's cross-section diverges from the central axis. Other alternative designs of the geometry of the racetrack will be described below, in connection with Fig. 3 and 4.

Fig. 3 shows schematically a sectioned, partial view of a grinding cell 30. The grinding cell 30 comprises two rotationally symmetrical bodies 31 and 32, axially aligned and with their opposed surfaces formed to define a circular racetrack 33. In an unspecified way, one of the bodies is driven to rotate in relation to the other body. In the racetrack 33 are hard ball blanks and softer balls, both referred to with the reference numeral 34 in the figure, positioned in a ring to follow the rotational motion of the bodies, under an axially applied load. The cross section of the racetrack 33 is essentially triangular for which both the outer and the inner periphery are diverging away from the central axis of rotation C. It is realised from considering fig. 3, the racetrack 34, within an interval, can hold ball and ball blanks of different sizes to be pressed against each other and against the inner, slanting periphery.

Fig. 4 shows schematically a sectioned, partial view of a grinding cell 40. The grinding cell 40 comprises two rotationally symmetrical bodies, one loading body 41 and one supporting body 42, axially aligned and journalled for relative rotation around an axis C. The lower body, in this embodiment the supporting body 42, has a cylindrical, partially conical core 43, which is slidably arranged in the centre of the stationary supporting body 42. The body 42 with the core 43 and the body 41 together define a circular racetrack 44 having a trapezoidal cross section. An axis 45 is centrally extended from the core, the body 41 being rotatably journalled on the axis near the top of the core 43. A driving means 46 drives the body 41 in rotation around the shaft 45 under the application of an axial pressure from a loading means 47. For the feeding with a grinding agent or grinding slurries containing grits and fluid, a channel 48 passes through the core 43.

It will be noted that because of the conical shape of the core 43, and its flexible bearing in the stationary body 42, the racetrack 44, within an interval, is permitted to receive balls and ball blanks of varying dimensions 49, 50 in contact against each other and against the periphery of the core, as well as against the loading body 41 and against the supporting body 42.

In the illustrated embodiment, balls and ball blanks are in contact with each other and with the three surfaces defined by the bodies building up elements constituting the grinding cell. Without any specific illustrations, it is realised that the racetrack may have a polygonal cross-section in which the balls or the balls and the ball blanks are in contact with four or more surfaces of e.g. a facetted racetrack. It is also realised that, the cross-section of the racetrack may be curved, concave or convex, either partially in the areas which are in contact with the periphery of the balls, or alternatively along sections or along whole peripheries of the racetrack.

For the grinding cell elements a material should be chosen which is elastic enough to be able to adapt in form to the size of both the soft balls and the harder balls, which normally initially has a larger diameter, in order to rotate these through the friction. The material should also be softer than the softer balls, and as en example can here be mentioned plastics or rubber, either for the grinding cell in its entirety or only partially on the surfaces which are in contact with the periphery of the balls.

CLAIMS

1. A method to machine and polish coarsely shaped ball blanks of hard materials to higher sphericity and surface smoothness, **characterised in** that the hard ball blanks are ground, under the addition of a grinding agent, against spherical balls of softer materials in grinding cells in which the hard ball blanks are forced to rotate and to slide against the adjacent spheres of softer materials.

2. A method according to claim 1, **characterised in** that the hard ball blanks and the soft balls are forced to rotate in a circular track under relative mutual sliding, both under a force directed axially towards the track, and under a force directed radially towards the centre of the racetrack.

3. A method according to claim 1, **characterised in** that the hard ball blanks and the soft balls are forced to rotate in a circular track under relative mutual sliding, both under a force directed axially towards the track, and under a force directed radially outwards from the centre of the racetrack.

4. A method according to claim 1, **characterised in** that the hard ball blanks are comprised of ceramic materials or cemented carbides and the soft spheres of metallic.

5. A method according to claim 1, **characterised in** that the grinding cell is constructed at least partly from an elastic material which is softer than both the ball blanks and the soft spheres.

6. Grinding cell for the machining and polishing of coarsely shaped ball blanks of hard materials to higher sphericity and surface finish by the addition of grinding agents, **characterised by** at least two rotationally symmetrical bodies (1,2;1',2';31,32;41,42), which are rotated relatively to each other under at least an axially directed load, the bodies being shaped to define a circular race track (3;33;44) for the housing and propelling of spherical balls

of softer materials under relative mutual rotation against ball blanks of harder materials.

7. Grinding cell according to claim 6, **characterised in** that the racetrack is designed to exert also a radially inwards directed force.

8. Grinding cell according to claim 6, **characterised in** that the racetrack is designed to exert also a radially outwards directed force.

9. Grinding cell according to claim 6, **characterised by** a supporting body and a relatively to this body axially aligned loading body, which bodies are rotationally symmetrically designed to define an ring shaped, in cross-section essentially triangular, polygonal, trapezoidal or curved volume, of which at least one, the inner or outer periphery, successively diverges from the centre axis of the grinding cell.

10. Grinding cell according to claim 9, **characterised in** that both peripheries of the ring shaped volume diverge in the same axial direction if the grinding cell, but at different angles to the centre axis of said grinding cell.

11. Grinding cell according to claim 9, **characterised in** that the soft balls and the hard ball blanks being in continuous frictional contact against three or more sides of the cross-section of the ring shaped volume, to be rotated with the relative motion of the supporting and the loading grinding cell bodies.

12. Grinding cell according to claim 9, **characterised in** that at least one of the supporting body or the loading body, entirely or partially, are manufactured from an elastic material which is softer than both the ball blanks and the soft spheres.

13. Grinding cell according to claim 9, **characterised by**: a supporting body (42); a loading body (41), which is axially aligned and moveable relative to the supporting body; a central core (43) of circular cross-section centrally and axially extended between the supporting body and the loading body; a loading device (47) to apply an axially directed load to the loading body; a power device

(46) for the rotation of the supporting and loading bodies relatively to each other; and a ring shaped track (44) defined by the loading body, the supporting body and the central core, dimensioned to hold the alternatingly arranged hard ball blanks and softer spheres in contact with each other and against the walls of the loading body, the supporting body and the central core and to bring them to slide relatively to each other.

14. Grinding cell according to claims 9 and 13, **characterised by**: a supporting body (42), a conical or at least partially cylindrical supporting core (43) having a top end thereof extended above a central top area of said body (42); an axis (45) extended axially from said top end of the supporting core (43) and connected to a loading means (47); a loading body (41) which is axially fixed but rotationally journalled on said axis (45) near the top end of the supporting core (43); a drive means (46) to rotate said loading body (41) on the axis, and channels (48) for supplying and removing, resp., of grinding agents.

15. Grinding cell according to claim 14, **characterised in** that the supporting body, the supporting central core and the loading body are manufactured from an elastic material which is softer than the spheres and the ball blanks, e.g. a synthetic material or rubber.

16. The use of spherical metal balls in a grinding method according to claim 1.

17. The use of ceramic balls, machined with a method according to claim 1, in ball bearings or pivots.

18. The use of a machining method according to claim 1 for the machining of pre-shaped, but not finally densified ball blanks.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 98/01662

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: B24B 11/02
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: B24B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI,EPODOC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 9520465 A1 (UNIVERSITY OF LEEDS), 3 August 1995 (03.08.95), figures 1,2, abstract --	1-18
A	DE 555753 A5 (OTTO KADZIK IN WIEN), 7 July 1932 (07.07.32) --	1-18
A	Tribolagy International, Volume 27, No.4, 1994, Influence of hardness of the counterbody in three-body abrasive wear - an overlooked hardness effect, N. Axén, S. Jacobson and S. Hogmark, pages 233-241, especially pages 239-241 --	1-18

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

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International application No.
PCT/SE 98/01662

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	IDR, 3/94, T.H.c. childs, MAGNETIC FLUID GRINDING OF CERAMIC BALLS, A, pages 120-123	1-18

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INTERNATIONAL SEARCH REPORT

Information on patent family members

01/12/98

International application No.
PCT/SE 98/01662

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9520465 A1	03/08/95	AU 687078 B	19/02/98
		AU 7232194 A	28/02/95
		EP 0711246 A	15/05/96
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DE 555753 A5	07/07/32	NONE	